BNL-65569

Conclusions of the Workshop*

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During this Workshop, it was concluded that a Proton-Proton Collider with an energy of 100 TeV per beam and a luminosity of about 10^{35} cm^{-2} s^{-1} is feasible. The most important technical requirement for the realization of such a project is a large bending field. For instance, a field of 13 Tesla would be desirable. This is twice the field of the SSC superconducting magnets, which very likely may be achieved in a non-too-far future by extrapolation of the present technology. The design of this Collider would follow very closely the methods used for the design of the SSC and of the LHC, with the major noticeable difference that, because of the larger bending field and the larger beam energy, the performance is determined by the effects of the Synchrotron Radiation in the similar manner they affect the performance of an electron-positron collider. This fact has considerable beneficial consequences since it allows the attainment of large luminosity by reducing the beam dimensions at collision and by requiring, to some degree, less number of particles per beam. On the other end, the losses to synchrotron radiation are to be absorbed by the cryogenic system, and the vacuum system should be capable to cope with them. A more significant rf system may also be required.

A possible pre-conceptual design has also been offered, based on the choice of a bending field of 13 Tesla, a beam energy of 100 TeV, a circumference of 220 km and a luminosity of 2.5 x 10^{34} cm^{-2} s^{-1}. Table 1 gives the list of the most important parameters for such a Collider. A possible arrangement is shown in Figure 1. The two storage rings would be housed in the same tunnel placed vertically on top of each other (as in the SSC), and made to collide as shown (Figure 2) in four major interaction regions. Each interaction region is 10 km long. Four utility straight sections (each 4 km long) are also provided for injection, beam abort, location of the rf cavities and other equipment. The angle separation between the several insertions is as shown in Figure 1. The overall dimension are 66 km by 74 km. The complex would fit nicely in the western part of Sicily, south of the city of Palermo as shown in Figure 3. There is no need for the Collider to lay exactly on a plane, but it can be made to follow the elevation of the terrain, if required, since the effects on the beam trajectory and dimension can be easily estimated. There shouldn't be even a concern about telluric movements as those caused by rare earthquakes, since the closure of the rings can always be reestablished after a major catastrophic event, in the same way it has been done, for instance, with highways and bridges in California. The area is also well served by an efficient network of highways and utilities. Sicily could capitalize indeed from such a major project.

Aside from the realization of the 13 Tesla superconducting magnets, the most crucial technical challenge of the hardware systems is given by the refrigeration system and the vacuum system which are to absorb a considerable amount of power lost to synchrotron radiation, and by the rf cavity system designed to provide the minimum of interaction with the beam and to control the possible manifestation of coupled-bunch instabilities.

*Work performed under the auspices of the U.S. Department of Energy

Another major concern deals with the injector to the collider. It is desirable to keep the energy range factor from one system to another to around ten to avoid consequences caused by the persistent currents and the saturation effects of the superconducting magnets. Thus, it advisable to inject at an energy of 10 TeV, that alone represents a major system, comparable to the Large Hadron Collider. A possible outline of the injector complex is shown in Figure 4. It is made of a Linac and of Low, Medium, High and Very High Energy Boosters chained to each other. A possible selection of the energy parameters is shown in Table 2. The HEB and VHEB are made of superconducting magnets.

From the beam performance point of view there are three major areas of concern: the coupled-bunch instabilities, for which one needs a careful design of the rf cavity systems and of an active damper system, the individual bunch instability and the beam-beam interaction.

As shown in Table 1, the limit on the longitudinal coupling impedance is expected to be a fraction of a ohm. The attainment of such low figure of the entire frequency range, especially for low frequency values would present a problem. On the other end, the longitudinal bunch dimension is of only few millimeters at most. To create a coherent instability within the bunch, only those wavelengths which are comparable or smaller than the bunch length are relevant. Thus, the coupling impedance limit really applies only for those corresponding high frequencies in proximity or even above the pipe cut-off, and thus should not really be of any major consequence.

A canonical value commonly accepted for the beam-beam tune shift for safe operation of the collider is 0.003. The value given in Table 1 is twice as large. Different beam-bunch population and configuration could allow a smaller beam-beam tune-shift, if this is desired. On the other end, we should also rely here on the damping nature of the synchrotron radiation, like in the equivalent electron-positron colliders where larger beam-beam tune-shifts have been demonstrated.

It is of course still important to determine the stability of motion of a single particle under the effects of magnet imperfections and tolerances. An extensive error analysis, with the aid of numerical tracking of the motio, is also required as in the SSC and in the LHC Projects. Nevertheless, again, it is expected that the damping nature of the synchrotron radiation will have a beneficial effect and will cause a relaxing of the tolerances.

The cost is overwhelmingly important for a project of this size. It is possible to make an estimate of the cost of the collider alone, excluding the injector complex, by extrapolating from the experience acquired with the RHIC and SSC magnets. For this purpose we have generated Table 3, with data originally provided by Erich Willen (these proceedings). The Table is eventually suggestive of a phased approach. Starting with a collider circumference of 220 km, it may be possible to employ RHIC-type magnets with a maximum field of 5.4 Tesla which can be obtained with a single layer coil, a length of 18 m and an aperture of 40 mm inner diameter. This would allow a beam energy of about 40 TeV. By doubling the layer, adopting a cable width of 10 mm, instead of 15 mm as in RHIC, a magnet length of 20 m and an aperture of 32 mm, it may be possible to reach a beam energy of 60 TeV. This can be relatively easily obtained with the present available technology. The cost of the Collider including the tunnel, magnet, and cryogenic system is just about 3 billion US dollars (1996 value). The higher energy of 100 TeV requires the development of a new magnet on principles which will have to deviate from those working for the RHIC-SSC type of magnets. Thus, the cost estimate is more difficult, but it is not expected to exceed 10 billion dollars. This is only the technical cost of the components, to which other burden costs, of engineering, architectural and administrative nature, are to be added.

Table 1. A possible selection of the Eloisatron Parameters

Beam Energy, E	100	TeV
Circumference, $2\pi R$	220	km
Bending Field, B	13	Tesla
Bending Radius, ρ	25.66	km
Packing Factor, ρ/R	0.734	
Periodiciy	2	
Length of Interaction Regions	4 x 10	km
Length of Utility Straights	4 x 4	km
Equivalent Number of FOD Cells	488	
FODO Cell Length	450	m
Phase Advance per Cell	90	degrees
Betatron Tunes (H=V)	~122	
Bending Angle per Cell	12.87	mrad
Lattice β - max	768	m
Dipersion, η - max	3.92	m
Transition Energy, γ_T	~110	
Revolution Period, T0	733	μs
Injector Normalized Emittance	1	π mm mrad
Magnet Coil i.d.	32	mm
Number of Dipoles / Half Cell	10	
Length of Dipoles	20	m
Length of Regular Quadrupoles	5	m
Quadrupole Gradient	4,2	T/cm
rf Frequency	360	MHz
Harmonic Number	263,758	
Missing Bunches	5	
Bunch-to-Bunch Separation	5	m
Number of Bunches per Beam	43,960	
Peak rf Voltage	100	MVolt
rf Phase Angle	17.65	degrees
Synchrotron Oscillation Frequency	2.5	Hz
Crossing Angle	62	μrad
β^* (H=V)	0.5	m
σ^*	0.67	μm
Number of Protons / Bunch	5.1×10^9	
Total Number of Protons / Beam	2.2×10^{14}	
Luminosity	2.5×10^{34}	$cm^{-2}\ s^{-1}$
Radiation Damping Time, $\tau_E = \tau_\beta$	40.3	min
Energy Loss / Turn	30	MeV
Radiated Power / Beam	6.8	Watt/m
rms Energy Spread, σ_E / E	6.8×10^{-6}	
rms Equilibrium Emittance	8.9×10^{-7}	mm mrad
Beam-Beam Tune-Shift	0.006	
Individual Bunch Z/n Limit	0.13	ohm

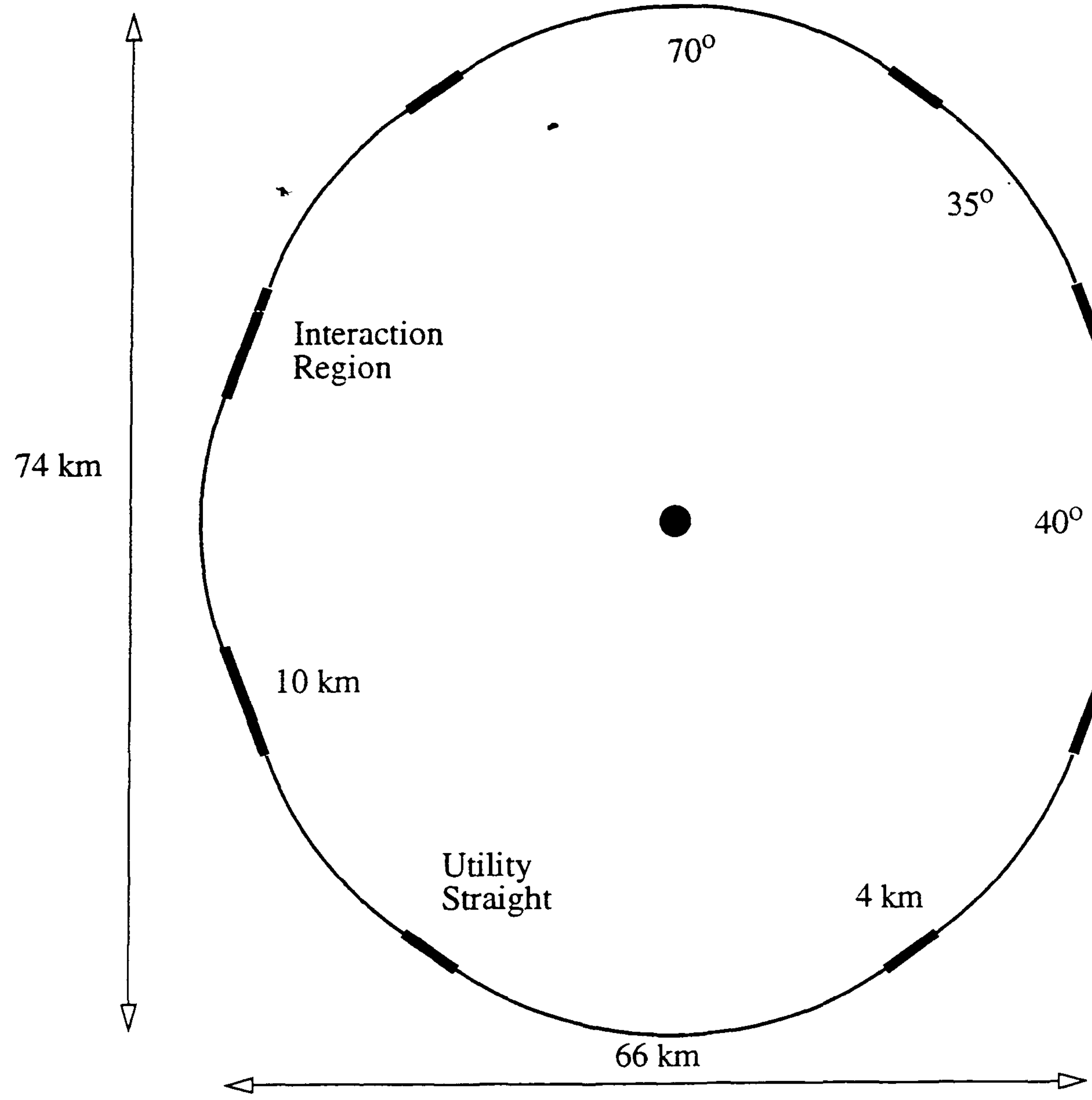

Figure 1. A possible Layout of the Eloisatron Collider

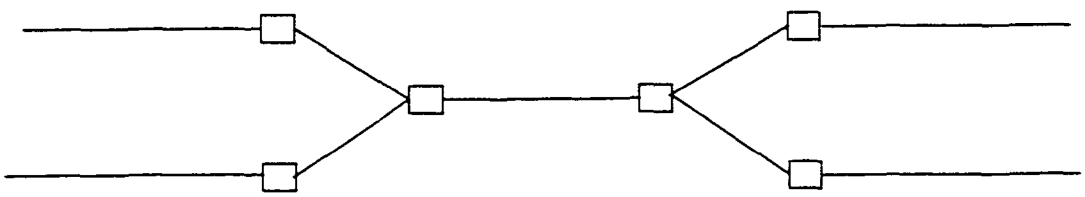

Figure 2. Two Intersecting Rings with Vertical Layout

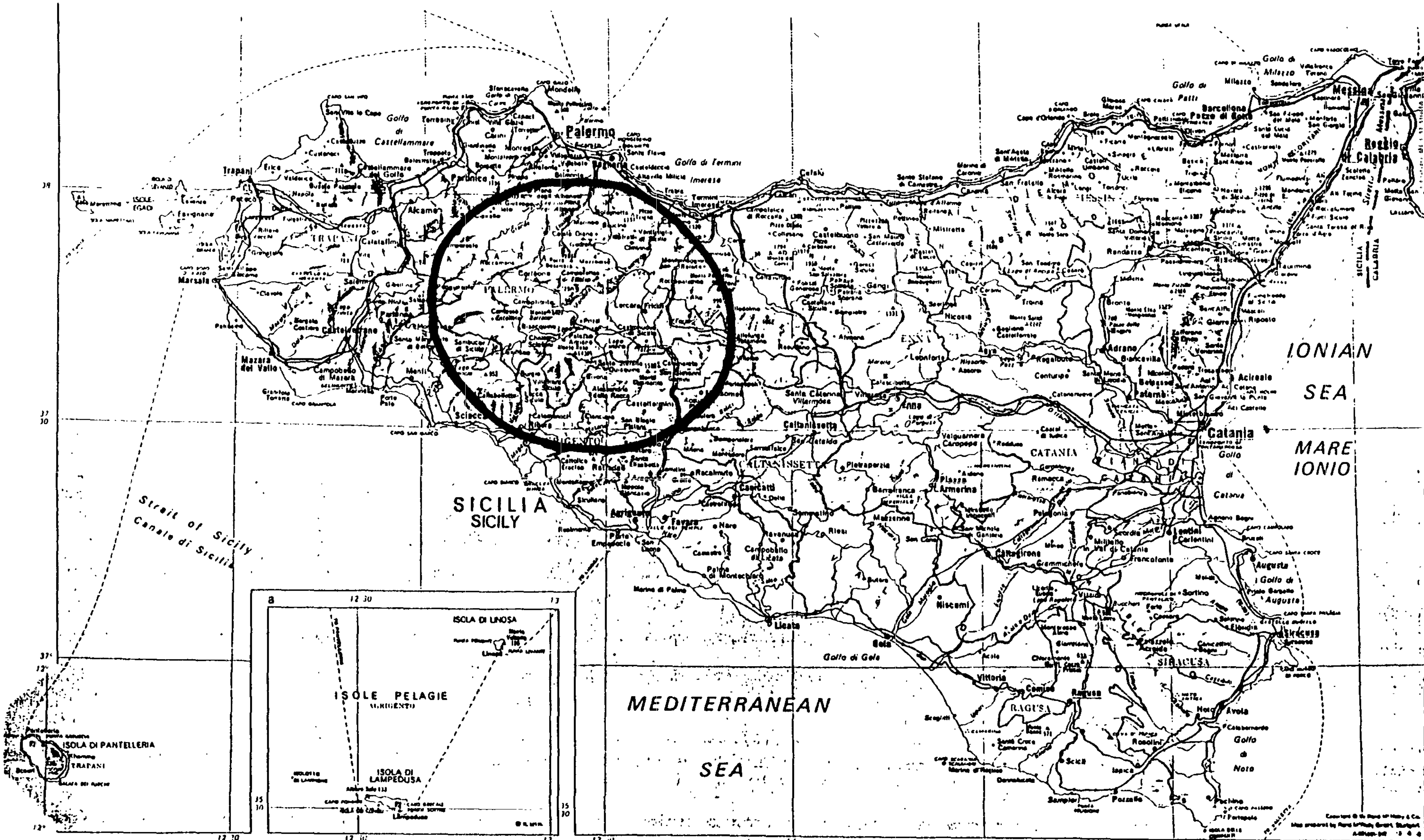

Figure 3. A possible Location of the Eloisatron in Sicily

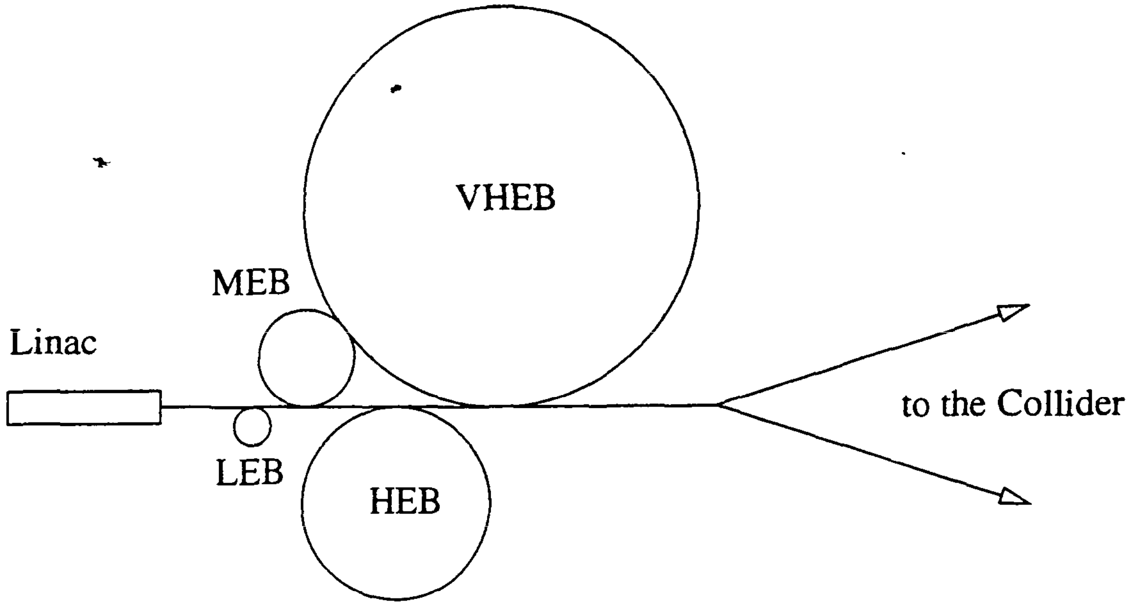

Figure 4. A possible Layout of the Eloisatron Injector

Table 2. Energy Range of the Injector Components

	Injection	Extraction	
Linac		1.2	GeV
LEB	1.2	12	GeV
MEB	12	100	GeV
HEB	0.1	1.0	TeV
VHEB	1.0	10.0	TeV
Collider	10.0	100	TeV

Table 3. Extrapolation of the Cost Estimate of the Eloisatron Collider.
Arc Dipole Magnets and Tunnel for 100 TeV

Type	B_0 Tesla	Cost \$/T-m	Dipole Cost Two Rings \$B	Length km	Tunnel Cost @ \$900/m \$M
RHIC 9.45 m length 80 mm aperture	4.30	2691	11.3	610	549
Adjusted Size 18 m length 40 mm aperture	4.30	1561	6.6	610	549
Adjusted Field Single Layer coil Cable 15 mm width	5.40	1436	6.0	486	437
High Field Cable 10 mm width 20 m length 32 mm aperture	7.72	1305	2.5	220	198